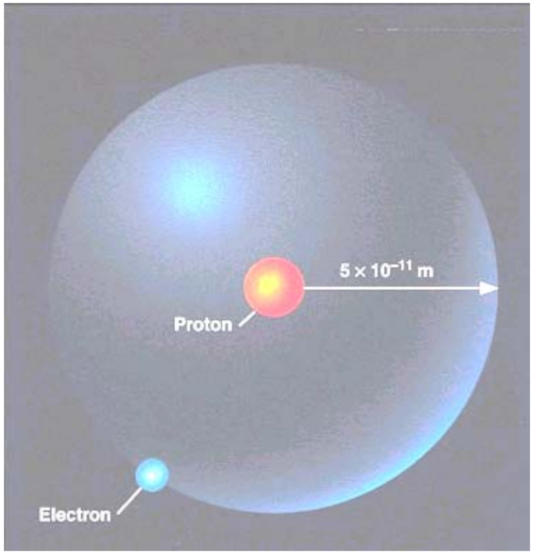
What Powers the Sun?

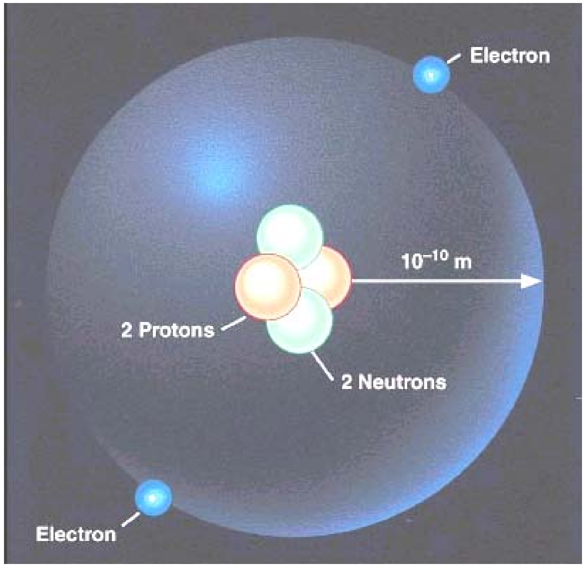
- Need to provide
  - 4×10^{26} watts
  - $< 2 \times 10^{33}$ grams (mass of Sun)
  - $>$ 4.5 billion years (age of Earth)
- Nuclear fusion reactions:
  - $4 \times {}^{1}H \rightarrow {}^{4}He$ + neutrinos + energy

Hydrogen: ^{1}H

4 x

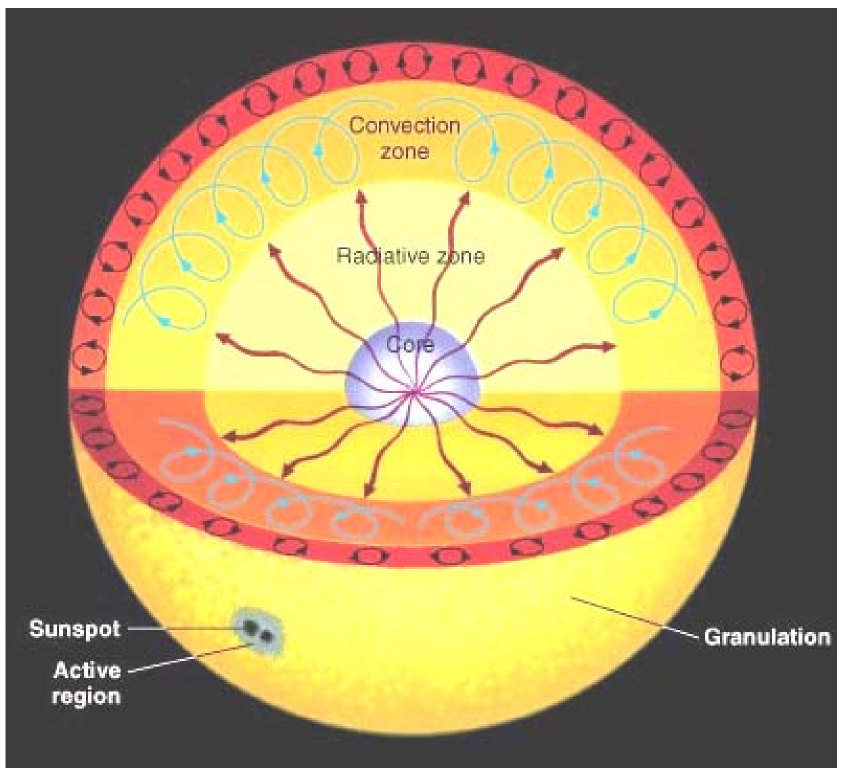


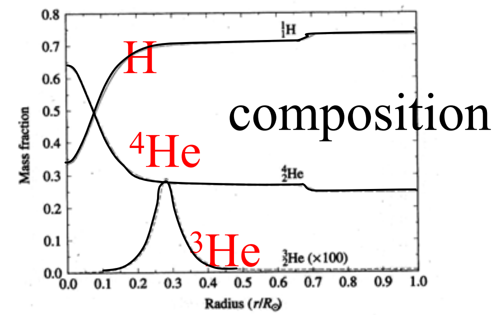
Helium: ^{4}He

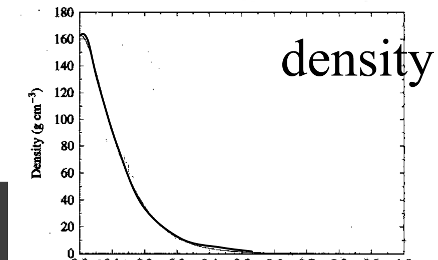


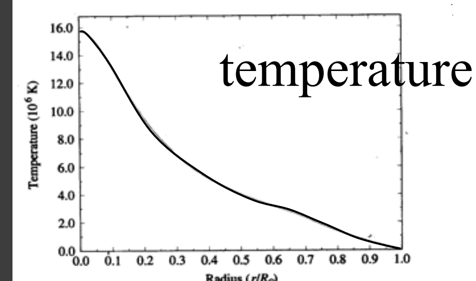
Computing the structure of the sun

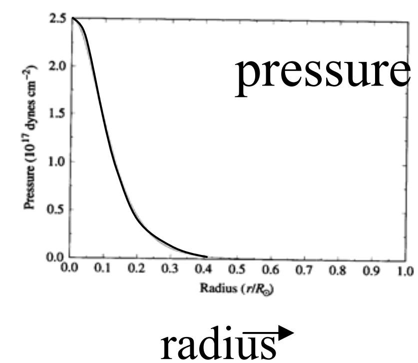
- For every point in the Sun, we want to compute
  - temperature
  - pressure
  - density
  - composition
  - energy generation
  - energy transport mechanism
- We can write 4 equations expressing the following ideas:
  - The Sun is a gas.
  - The sun is neither contracting nor expanding.
  - The sun is neither heating up nor cooling down.
  - Specify method of energy transfer.



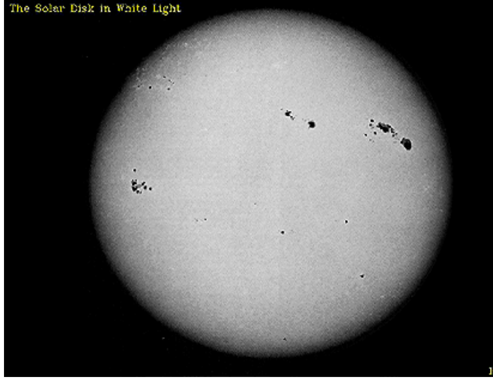


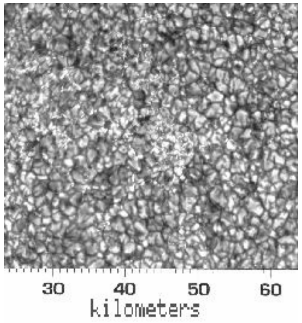




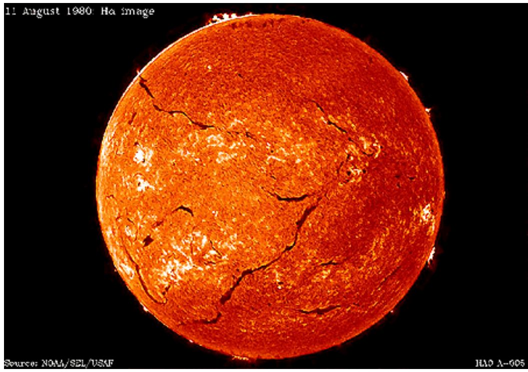


- Photosphere
  - Deepest layer from which light directly escapes into space.
  - Low density and pressure (10^{-4}, 0.1 x Earth's surface values)
  - But *hot* (5800° K)
  - Granules (in photosphere)
    - Tops of convection currents.

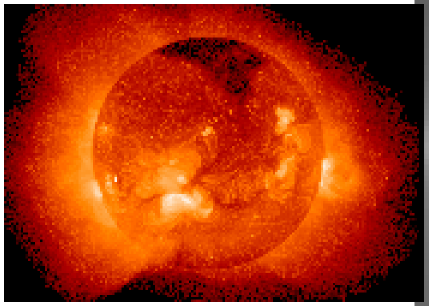


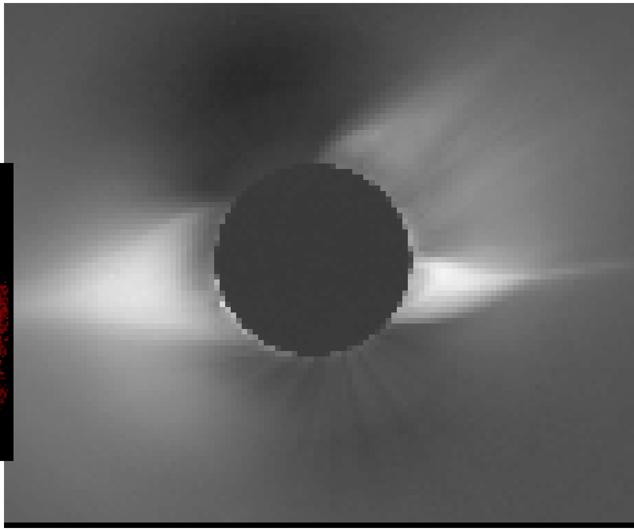


- Chromosphere
  - Transparent gas layer, reaches 2000-3000 km above photosphere.
  - T ~5,000-10,000° K
  - Photosphere = point we can no longer see through chromosphere.

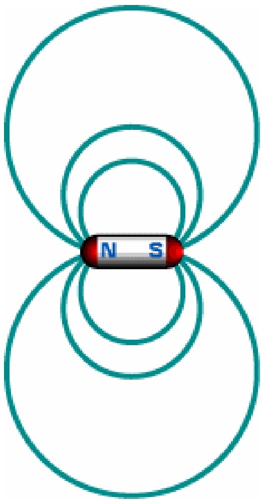


- Corona
  - T > 1,000,000° K
  - Very low density: 10^{-10} bar.
  - Heated by magnetic energy.
  - Several x diameter of photosphere.

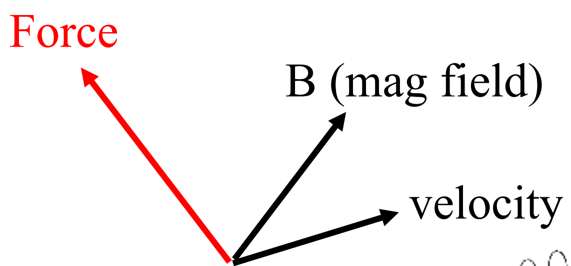




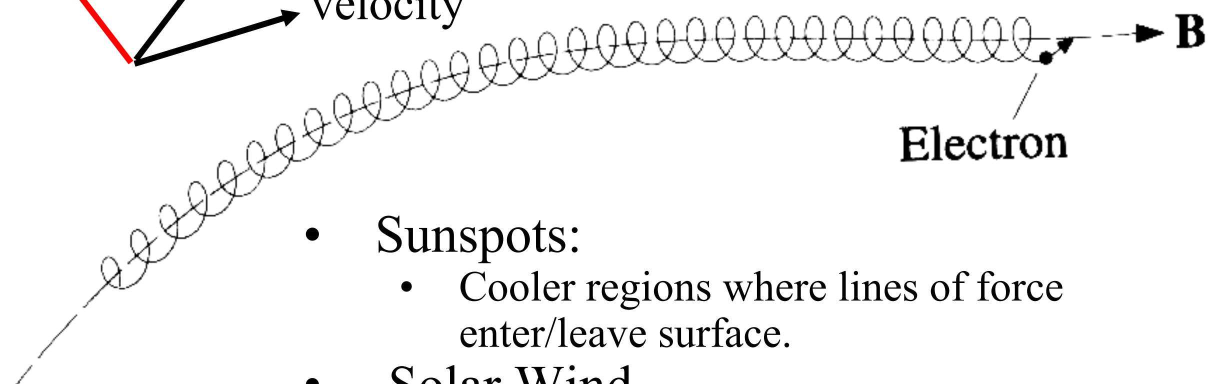
Magnetic Fields Control Much of Sun's Surface Activity



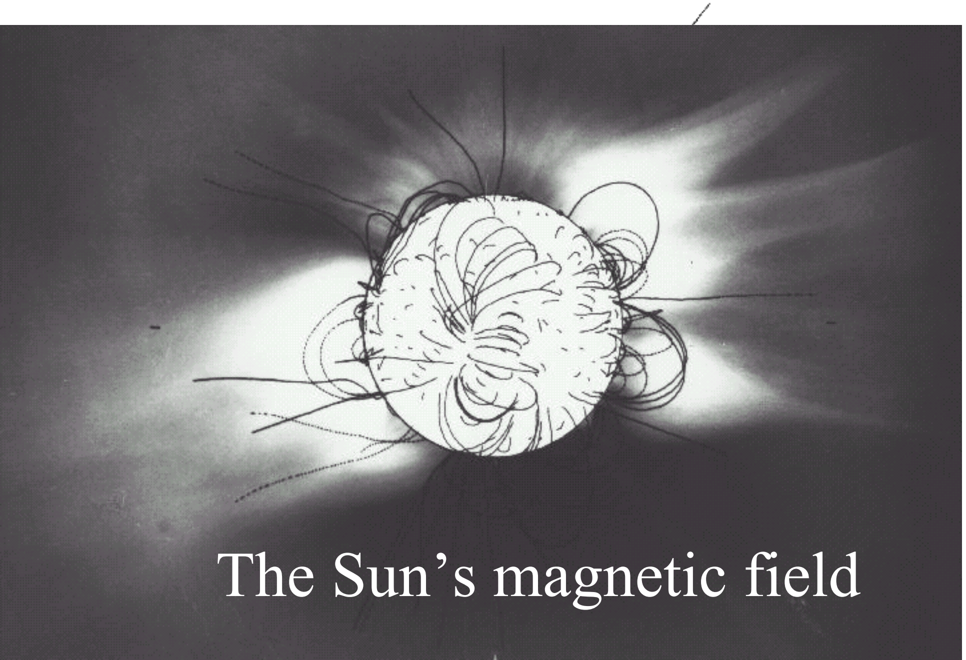
Magnetic field lines of force



Motion of a charged particle around a magnetic field line



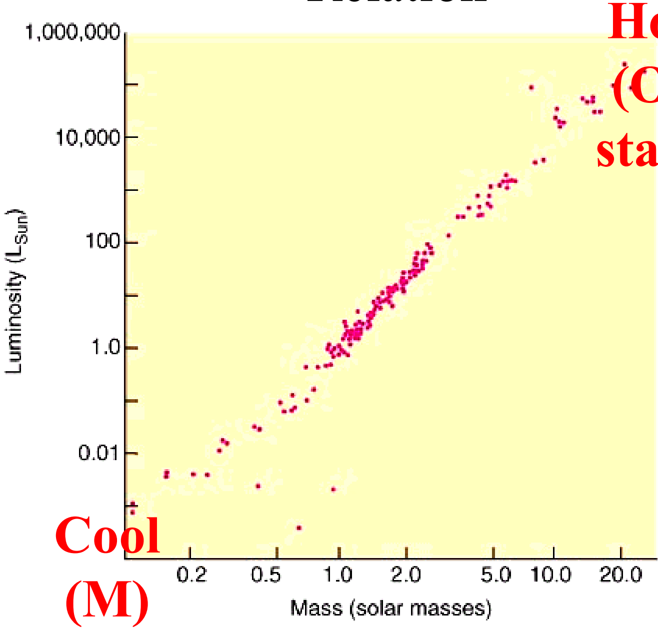
- Sunspots:
  - Cooler regions where lines of force enter/leave surface.
- Solar Wind
  - Charged particles with greater than escape velocity, escaping through holes in magnetic field.
- Prominences
  - Charged particles following magnetic lines of force.
- Flares
  - Magnetic field lines short out ➔ Huge burst of charged particles
- 11/22 yr. Solar cycle
  - Due to "winding up" of Sun's magnetic field.



The Sun's magnetic field

Here's what we observe about stars.

The Mass-Luminosity Relation



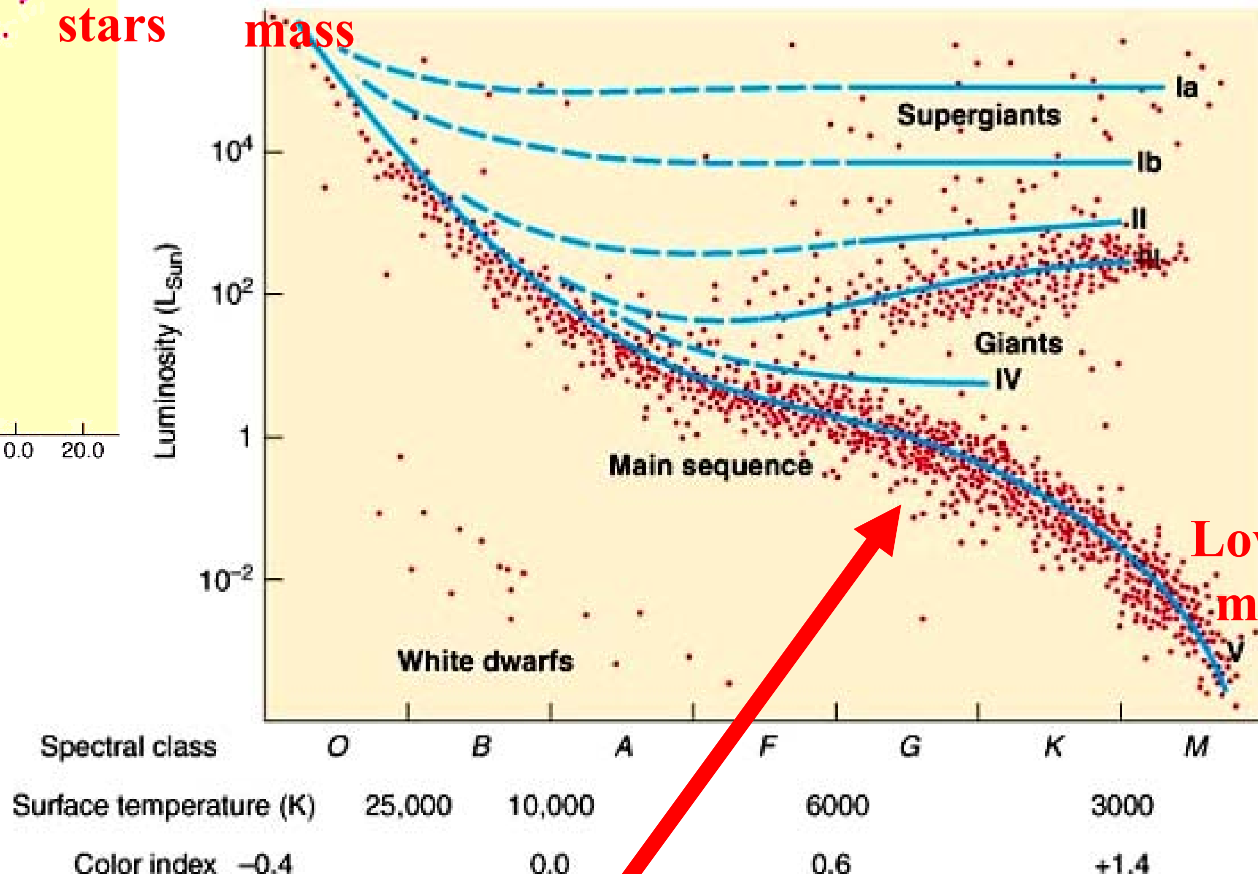
Hot (O) stars

Cool (M) stars

Main sequence is a mass sequence

The H-R Diagram
(Luminosity, Temperature, Radius)

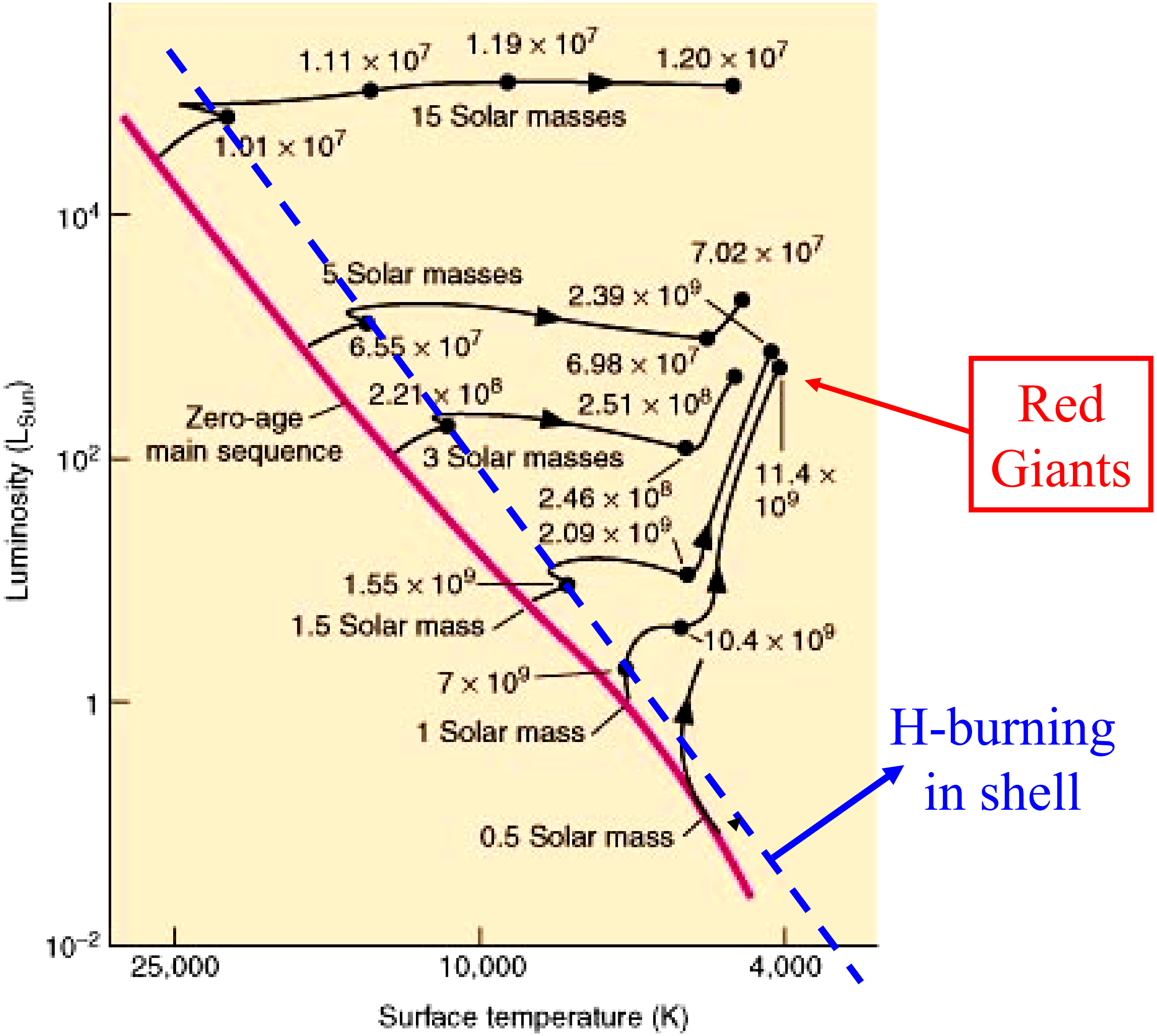
Higher mass



Lower mass

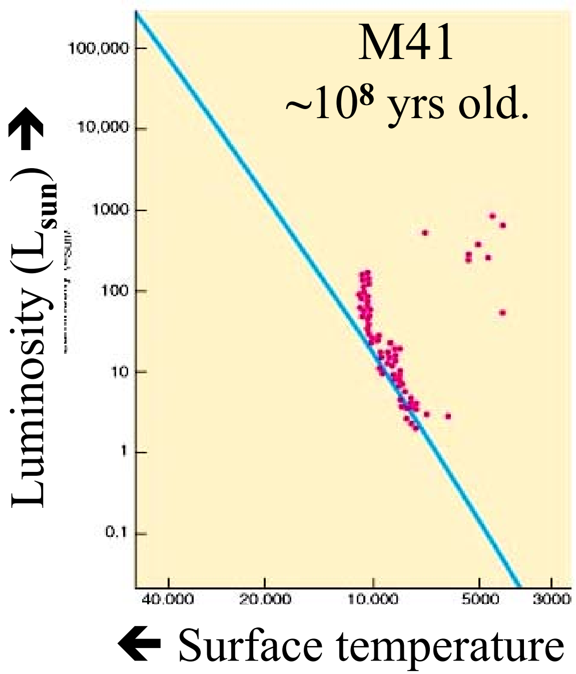
MAIN SEQUENCE:
Stars convert H into He in their cores.

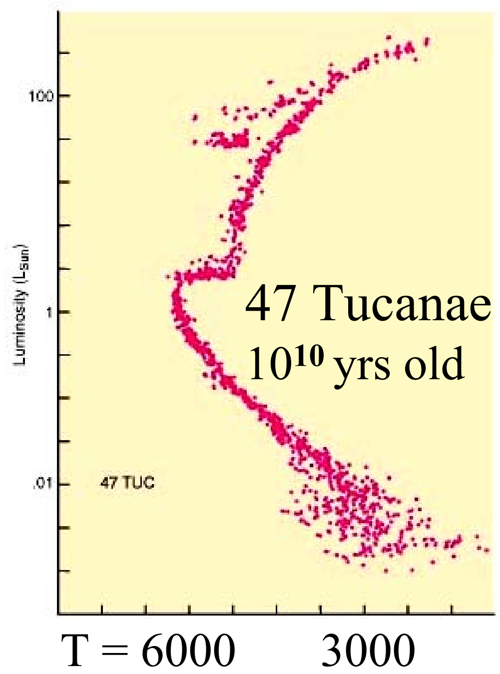
Predicted paths of stars on HR diagram



[see figs. 12.10, 12.12]

Star clusters are snapshots of stellar evolution





- All stars in a given cluster formed at ~ same time.
- But with a wide range in masses.
- ***Main sequence turnoff*** = stars just finishing main sequence evolution.

To see how it all works, look at:

http://www.mhhe.com/physsci/astronomy/applets/Hr/frame.html

http://www.pa.msu.edu/courses/isp205/sec-3/hr.mpg

Stellar Evolution

Here: Evolution through nuclear burning.	
$M_{initial} > 2M_{\odot}$	**Nuclear burning all the way to iron.**
$M_{initial} < 2M_{\odot}$	**Nuclear burning shuts off after He-flash.**

Mass loss: ➔

- Planetary nebulae
- Eta Carinae
- Supernovae

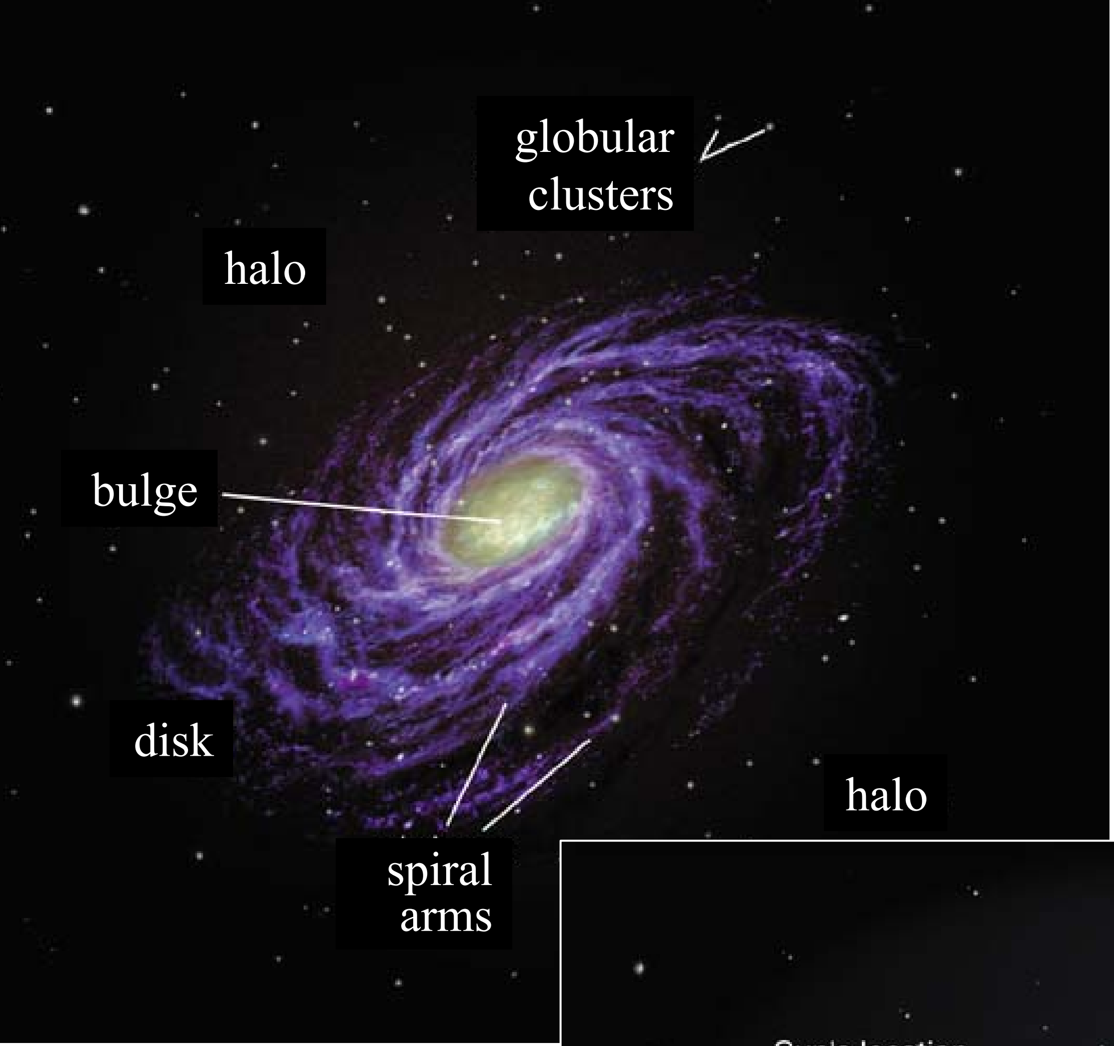
There: Final state.	
$M_{final} > 3M_{\odot}$	**Black hole.**
$1.4 < M_{final} < 3M_{\odot}$	**Neutron star.**
$M_{final} < 1.4M_{\odot}$	**White dwarf.**

Formation of stars (and planets)

- Molecular (gas) clouds
  - Up to $\sim 10^5$ $M_{\odot}$
  - 100's of LY in diameter.
- High density by interstellar medium standards
- Shielded from UV radiation by dust ➔ atoms are combined into molecules.
  - H_2 …and also CO plus other more complex molecules.
- Preferred place for stars to form.
  - In spiral arms of our Galaxy.

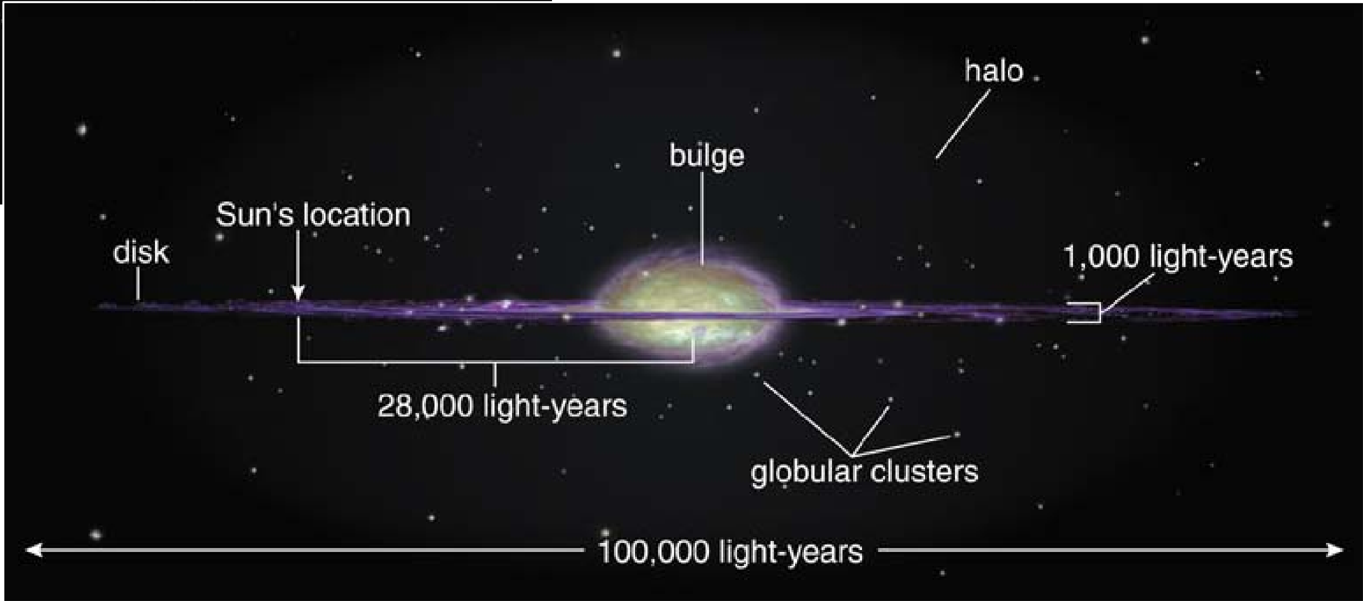
- Some examples of star forming regions, discussed in class:
  - Orion Nebula
  - M 16 Pillars of Creation
- Star formation ➔ disks around stars
  - Planets form in these disks.
- Planets around other stars
  - Over 100 known
  - Usually detected through their effect on motion of the parent star.
- Possible sites of life… in our Solar System? Elsewhere?

The Milky Way



- Gas, large fraction of stars in thin disk
  - ~1000 LY thick
  - Spiral structure
- Spherical halo
  - ~150 globular clusters
  - Spherical distribution of stars
- Nuclear bulge

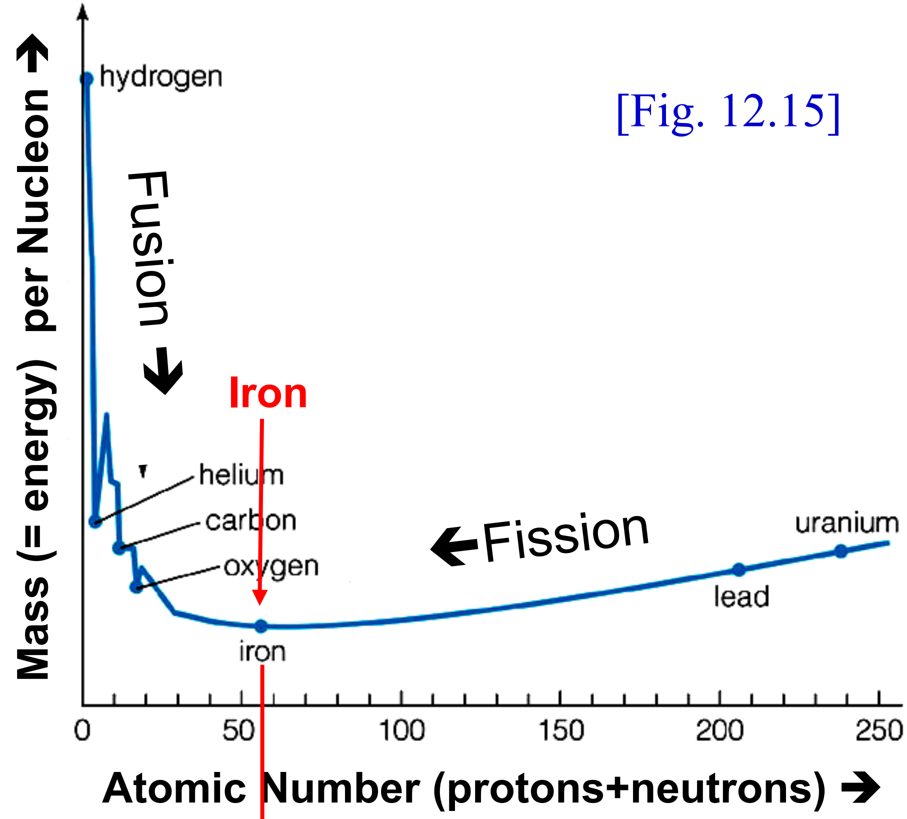
[Fig. 14.1]



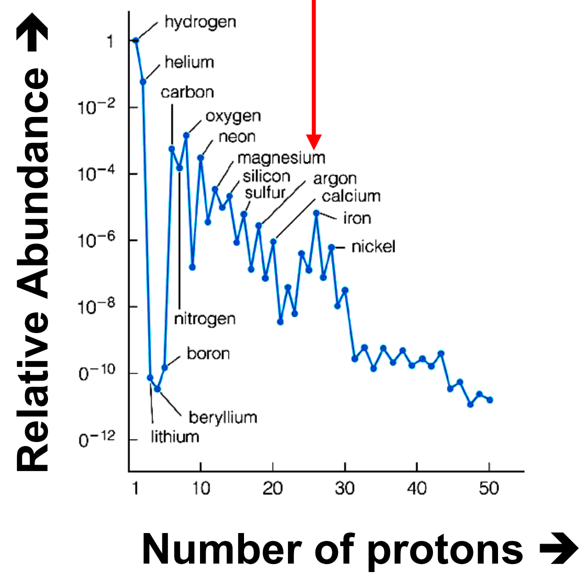
The chemical evolution of our Galaxy:

All elements heavier than H and He were made in *stars*.

- H ➔ He ➔ C,N ➔➔ Fe
  - Occurs in interiors of various types of stars.
- Fe ➔ heavier elements (U, etc).
  - In supernova explosions.
- Recycling back into interstellar gas
  - Planetary nebulae, supernovae, etc.



[Fig. 12.15]



[Fig. 12.16]